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An Investigation of the performance of gray-component replacement

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AN INVESTIGATION OF THE PERFORMANCE OF GRAY-COMPONENT REPLACEMENT

AN INVESTIGATION OF THE PERFORMANCE OF GRAY-COMPONENT REPLACEMENT

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing Management and Science in the College of Graphic Arts & Photography of the Rochester Institute of Technology

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TABLE OF CONTENTS

Chapter		Page
	LIST OF TABLES.	iii
	LIST OF FIGURES	iv
	ABSTRACT.	1
ONE	INTRODUCTION.	1
	The Problem	
	Significance and Background	
	Footnotes for Chapter One	
TWO	THEORY.	13
	Footnotes for Chapter Two	
THREE	LITERATURE REVIEW	24
	Footnotes for Chapter Three	
FOUR	HYPOTHESES.	31
FIVE	METHODOLOGY	33
	Survey Questionnaire	
	Footnotes for Chapter Five	
SIX	DATA ANALYSIS	41
	Footnotes for Chapter Six	
SEVEN	DISCUSSION OF RESULTS	56
EIGHT	SUMMARY AND CONCLUSIONS	59
	Footnote for Chapter Eight	
NINE	RECOMMENDATION FOR FURTHER STUDY.	62
	BIBLIOGRAPHY.	63

LIST OF TABLES

Table		Page
	HYPOTHESIS I	
1.	Data from survey question 1.	43
2.	Data from survey question 2.	45
3.	Data from survey question 3.	46
4.	Data from survey question 4.	47
5.	Data from survey question 5.	49
	HYPOTHESIS II	
6.	Data from survey question 1.	51
7.	Data from survey question 2.	53
8.	Data from survey question 3.	53
9.	Data from survey question 4.	54
10.	Data from survey question 5.	54

LIST OF FIGURES

Figure		Page
1.	GRAPHIC EXAMPLE: The achromatic value (neutral area) is replaced by black.	16

ABSTRACT

Members of the graphic arts industries are slowly becoming aware of undercolor reduction techniques used in the attempt to help stabilize high speed wet printing. Undercolor removal is a color correction method which follows this line of thought as it reduces the amount of ink coverage by the process-color inks and increases ink coverage of the black printer in the darker neutral areas of a reproduction. The advantages realized by this technique are carried even further with gray-component replacement (GCR). GCR removes the process color inks that make up a dark tone and replaces them with black ink in both neutral and color regions of a reproduction. This separation method provides technical and cost benefits to the printer.

An investigation of this reproduction technique forms the basis of this research project. A comparison was made between the quality performance of gray-component replacement techniques and the traditional four-color reproduction method. It was found through visual subjective testing, while not all the tone reproduction criteria favored the traditional four-color reproduction method, color and print contrast were affected by the use of gray-component replacement.

CHAPTER ONE

INTRODUCTION

The Problem

The purpose of this research was to investigate the quality of process color reproductions produced from color separations which are prepared using achromatic color reduction techniques. Achromatic color reduction is a color correction method which removes very dark tones reproduced with the three process inks and replaces them with black ink. The achromatic portion of a hue, or the color least used to represent a tone, determines the black replacement. This technique is possible from the highlight to the shadow regions of a reproduction, unlike undercolor removal (UCR) which only allows reduction in the darker neutral gray areas of a reproduction.[1] The term achromatic color reduction is a generic name used by the author to define color correction techniques based on achromatic color theory; this broad term includes company trade names for simultaneous reduction methods in the color and neutral areas of a reproduction as well. Different manufacturers use different terminology for this process such as: complementary color reduction (CCR), programmed color reduction (PCR), and integrated color reduction (ICR).

Terminology has become a problem throughout the printing industry as European and American counterparts refer to this process using a wide variety of names. The Germans named this technique "unbuntaufbau", which translated means achromatics. As stated in an article written by Franz Sigg and Patricia Cost, "achromatics" or phrases that include the term "achromatic" are misleading because achromatic means "without hue or saturation". The terms achromatic reduction or removal have become quite popular nonetheless. Sigg and Cost also state that "removal" and "reduction" are unsuitable names because they do not explain the entire process, ignoring the replacement of inks which actually occurs. These authors took a poll of industry professionals and faculty and staff at RIT and settled on the term "gray-component replacement", or GCR, as the most suitable terminology to describe this ink removal and replacement.[2]

A paired comparison method of testing was used as a random selection of viewers compared color reproductions using varying percentages of gray-component replacement to a traditional four-color reproduction prepared without the use of any undercolor removal. A traditional or conventional four-color reproduction, as referred to throughout this paper, was produced with a color separation set in which the gray scale was reproduced with the three subractive primaries: cyan, magenta, and yellow. A skeleton black printer was used to give neutrality and print contrast.[3]

Both sets of reproductions were also compared to the original transparency. Comparisons were focused on such tone reproduction qualities as detail, contrast, and color rendition. Correlation of the research data was used to try to find a level or threshold amount of GCR that produces acceptable quality when compared to a conventional four-color reproduction. The question as to which reproduction method more accurately reproduces the original transparency is also under investigation.

Significance and Background

Again, the quality performance of gray-component replacement techniques will form the basis of this research project. Before discussing the theory behind GCR, it is necessary to point out significant paths taken in four-color reproduction that lead to this new color separation technique. The use of tri-color filters, red, blue, and green, has proven very successful for three-color photography and printing. Subtractive three-color photography shows that the printing colors of cyan, magenta, and yellow should be sufficient, in theory, to reproduce the full range of colors existing in an original copy.[4]

Combinations of the subtractive primaries, cyan, magenta, and yellow, should achieve the necessary colors to reproduce original colored artwork, as well as achieve proper gray balance. "Gray balance is the ability to produce a given neutral gray of a certain visual density as measured with the visual densitometer. This gray has no apparent color cast, even though it is produced with cyan, magenta, and yellow dots of different sizes."[5] Achieving proper gray balance is an important requirement for good tone reproduction, and in turn, good color reproduction. "Tone reproduction is the visual and photometric relationship of neutral grays on the original copy to the reproduced neutral grays."[6] Color areas of a set of separations can be color corrected to compensate for ink deficiencies by corrective masking or electronic scanning color correction techniques, but neutral gray areas of the reproduction depend on proper screening of the separations to achieve gray balance. The amounts of yellow and magenta, as compared to cyan, are reduced so neutral grays are reproduced as neutral grays, not muddy browns.[7]

Three-color printing can produce acceptable results; the addition of a poor black printer can reduce quality if care is not taken. Most commercial printers do use a black printer in addition to the other three to help achieve neutrality and increased shadow detail. This black printer can in some cases darken the reproduction or cause a flat, muddy appearance if too much black is used or if proper corrective measures are not applied. Undercolor removal (UCR) is a method of correction used in making process-color separations which "consists of making room for the black by reducing the amount of the other three colors wherever black is to be printed".[8]

As stated by J.A.C. Yule, in his Principles of Color Reproduction, there are four chief reasons for using a black printer:

1. To make the control of the other three colors less critical in regard to ink balance.

2. To produce denser blacks and better shadow detail than the other three colors alone can produce.

3. To substitute a relatively inexpensive black ink for a part of the more costly colored inks.

4. In high speed wet printing, to avoid the piling up of several inks which do not print satisfactorily on top of each other.

In other words, "the object of the black printer is to supply the density, contrast or detail which is missing from a three-color print", while aiding in the stabilization of high speed, wet-on-wet printing.[9]

"In high speed wet printing, where all four colors are printed together without allowing time for each ink to dry before the next ink is applied, it is not possible to apply the large amounts of ink required to produce a black with three colors."[10] Because of this, undercolor removal is necessary. When UCR is applied, a portion of each process color in the shadow areas is reduced and replaced with black. "This is possible because the gray areas are reduced in proportional amounts, which maintains the gray balance but produces a lighter gray. The black is increased in these areas to exactly compensate for the cyan, magenta, and yellow that are removed."[11] When the printing dot size for each process color is reduced, the black printing dots must be increased by the same amount. For example, if a normal reproduction uses printing dot size amounts consisting of a 97% cyan shadow dot, a 90% magenta shadow dot, a 90% yellow shadow dot, and an 80% black shadow dot, the use of 10% UCR would lower the shadow dot sizes in the darker neutral areas of the reproduction to 87% cyan, 80% magenta, 80% yellow, and increase the black shadow dot to 90% area coverage. UCR is being used to reduce the shadow dot sizes by 10% and at the same time increase the black shadow dot area by 10%.[12]

A problem can arise from the fact that the percentage of shadow dot area of the black separation can only be increased to 100%; this is one reason why extreme amounts of UCR cannot be used. Another drawback is seen if too much undercolor is removed. The density in the gray areas of the reproduction begins to decrease instead of increase from highlight to shadow. This phenomenon is referred to as a reversal. The scanner operator may have to decrease the density of the midtones to control a reversal. This however, can change the contrast of the reproduction.[13]

The reduction of printing dot area by UCR helps stabilize high speed printing by improving trapping problems, ink set-off problems, and ink drying problems. For these reasons, the Recommended Standards for Web Offset Publications (SWOP) was issued in 1975 to help standardize web offset for publications printing. The SWOP specifications state that "for four-color printing the sum percentage of tone values should not exceed 280% as long as the area is not larger than one square inch. Four-color films should be made with the least amount of overprinting possible to avoid excessive mixing of inks."[14] Four colors should not be used when three or less will produce the same desired results. The 280% total ink coverage demanded for publication printing is achieved by employing an appropriate amount of UCR. In order to reach this standard, close to 30% undercolor removal is required.

The advantages seen by the use of UCR have been carried even further with gray-component replacement. With more advanced technology, instead of limiting color removal to the neutral gray areas of a reproduction, the black printer becomes significantly more important as it prints in both colored areas and neutral areas. This "technique is used to remove the black tones of a process color reproduction that are reproduced using process inks and replaces them with black ink".[15]

As efforts to standardize high speed offset printing continue, GCR becomes the basis for this new color correction technique which concerns itself with many of the problems found in high speed, wet-on-wet printing. (These problems will be discussed in a later chapter.) This alternative to the conventional reproduction method intends "to apply less colored ink on the material to be printed, while retaining maximum stability and consistency and without adversely affecting the force of the color and the contrast".[16]

The achromatic method is "diametrically opposed" to the presently employed chromatic method of color separating and printing.[17] This new method is a color reduction method which goes much further than does the currently used gray undercolor removal (UCR). One of the leading graphic systems manufacturers, The Hell Company, takes the point of view that from a printing standpoint, "there are few reasons for darkening a color tone from the tertiary, (of third rank or importance), color range with a colored ink. The black ink can achieve the same result by replacing that primary color which is least used in representing a tone".[18]

Comparison between a conventional four-color reproduction, using no undercolor removal, and reproductions separated by the use of different percentages of gray-component replacement formed the basis of this research project. This was an investigation to find a level of GCR that compares favorably with conventional four-color reproductions. The research also proposed to determine which method for process color separation more perfectly reproduces the original transparency. If GCR is to become commercially successful in process color printing, it is important to determine whether greater ease of printing and cost savings are worth the possible risk of reproducing lower quality color reproductions. The previously mentioned goal of applying less colored ink on the substrate can be helpful in the standardization of offset printing. It can also offer clear economic advantages, if maximum stability and consistency can be retained during printing and if color and contrast remain unaffected. The theory behind gray-component replacement will be discussed in further detail in the following chapter of this paper.

FOOTNOTES FOR CHAPTER ONE

[1]Peter Dacuik, Technical Specialist, Hell Graphic Systems, Inc., White Plains, New York, January 1984.

[2]Patricia Cost and Franz Sigg, The T & E Center Newsletter, Vol. 12, No. 6, (Rochester Institute of Technology, Rochester, New York, 1984), p. 5.

[3]Dr. Eggert Jung, Programmed and Complementary Color Reduction, (1984 TAGA Proceedings, Technical Association of the Graphic Arts, 1984), p.138.

[4]J.A.C. Yule, Principles of Color Reproduction, (New York: John Wiley & Sons, Inc., 1976), p. 282.

[5]Miles F. Southworth, "Gray Balance and Tone Reproduction for Color", The Quality Control Scanner, Vol. 2, Number 3, (Livonia, New York: Graphic Arts Publishing Co., 1981), p.1.

[6]Ibid.

[7]Ibid.

[8]J.A.C. Yule, Principles of Color Reproduction, (New York: John Wiley & Sons, Inc., 1976), p. 282.

[9]Ibid. p. 283.

[10]Ibid. p. 295.

[11]Miles F. Southworth, "Undercolor Removal (UCR)", The Quality Control Scanner, Vol. 2, Number 7, (Livonia, New York: Graphic Arts Publishing Co., 1981), p. 3.

[12]Ibid.

[13]Joseph L. Noga, Scanner Seminar Class Notes, Rochester Institute of Technology, Winter, 1984.

[14]American Association of Advertising Agencies; American Business Press; Magazine Publishers Association, Recommended Specification Web Offset Publications, February 1981, p. 2.

[15]Miles F. Southworth, "Hell Has Programmed Color Removal (PCR)," The Quality Control Scanner, Vol. 3, Number 6, (Livonia, New York: Graphic Arts Publishing Co., 1983), p. 4.

[16]"PCR: Programmed Color Redution from Hell", The Hell Company, 1983, p. 1.

[17]M. Winfried Lauenstein, "The Achromatic Method: What Changes Does it Bring?", presented at the XXVIIth. International Congress, Union des Industries Graphiques de Reproduction, Cannes, France, 30 April 1983, p. 1.

[18]"PCR: Programmed Color Reduction from Hell", The Hell Company, 1983, p. 1.

CHAPTER TWO

THEORY

Interest in undercolor reduction techniques has grown as manufacturers continue to improve electronic color separation equipment and color computer programs that process the necessary calculations for color reduction. The older electronic scanners are already capable of color reduction in the darker neutral gray areas of reproduction. Color reduction, as practiced until recently, was restricted to neutral areas of a reproduction, however a push has been made by manufacturers to change this with the modification of color computer programs that not only calculate color reduction for dark neutrals, but also for the reproducible color range. This method is referred to as gray-component replacement. Attempts at any undercolor removal, without the appropriate hardware or software for GCR, in non-neutral areas will change the hue of a color considerably. Now with digitally stored tonal gradations on disc, the color computer can change gradations in neutral areas separately from those in non-neutral areas of the separation.[1]

One manufacturer, The Hell Company, employs the achromatic technology in its computer software and hardware extension. The system is called "PCR" (programmed color reduction). Hell claims the solution for many printing problems with the use of PCR, "which will bring greater stability to the fluctuating offset run."[2] These advantages read as follows:

1. The tones and gray balance are less sensitive to fluctuations in the ink during printing.

2. The greatest plague of wet-on-wet printing, inadequate color acceptance, has been largely removed.

With regard to better quality of the printed reproduction, use of Hell's PCR means:

1. The primary colors making up the bright value in the tertiary colors are more highly saturated.

2. The print contrast is better since the usually excessive degree of area coverage of the colored inks is reduced and they no longer obstruct one another in the coloration.

There are also concrete economic advantages:

1. Wherever less colored ink is printed, the degree of area coverage decreases, along with the ink costs and drying energy required.

2. Higher productivity as a result of shorter set-up times and less waste.[3]

To compare the basic theory between gray-component replacement and the traditional four-color reproduction method, it is necessary to first understand that every color produced by the three primary colors can be divided into two portions, an achromatic portion and a chromatic portion. The chromatic portion is made up of one or two primary colors and always gives the desired hue its colored appearance. For example, magenta ink can be printed to reproduce a magenta object or magenta and cyan can be printed together in various amounts to reproduce a shade from blue to purple. When using gray-component replacement, the chromatic portion of the color hue should be unaffected. Chromatic composition is produced by varying amounts of cyan, magenta and yellow. These three inks are responsible for neutralizing each other to produce the achromatic portion of the color (the neutral gray portion). With GCR, the achromatic portion depends on the black ink only for its achromatic value. The difference lies in the fact that with GCR, there are never more than two process color inks plus a black ink overprint. This means changes in the black ink would only lighten or darken a color hue instead of changing the saturation of the color.[4]

The gray-component replacement technique:

> prints black ink in both colored areas and dark neutral areas. For example, the overprint red color of a printed apple needs approximately 95% magenta, 80% yellow, and 20% to 40% cyan halftone dots to give the reproduction the proper hue and tonal reproduction.[5]

Following this example, the cyan ink, which is the least used of the three inks to represent an apple red color, absorbs the red light; black, with a small amount of cyan, will also absorb red light. This means that some of the cyan ink can be replaced by black ink. If 100% GCR is used, all the cyan ink is replaced by black. In theory, the black can totally replace all three chromatic inks in the shadow areas and replace the least dominant color throughout the entire reproduction.[6]

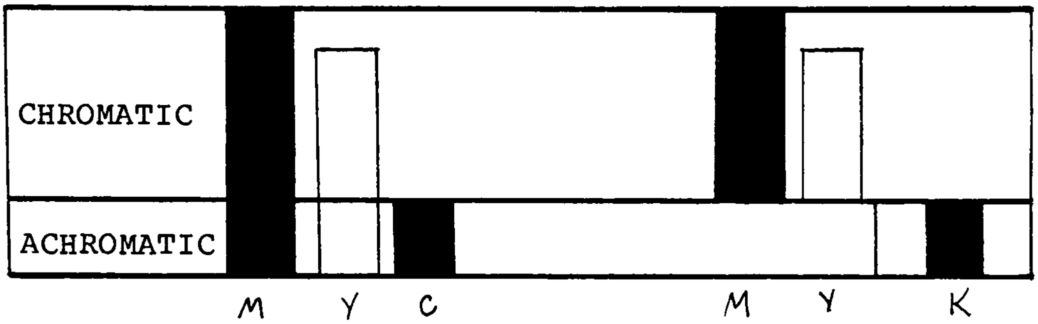

Figure 1 -- The achromatic value (neutral area) is replaced by black

Color separation is performed on a three-signal scanner as the black signal is subtracted from the color signals. "In theory this already meets achromatic structure requirements because the black signal is the same as the signal of the primary color contributing least to a tertiary hue."[7] Individual printing conditions control the amount of black that will replace the signal which contributes the least to the reproduced shade. Special modified calculations, like those used for The Hell Company's PCR software, take into account individual printing conditions to convert printing ink signals for magenta, cyan and yellow into the necessary signals for producing an achromatic reproduction. Individual printing conditions include such things as: substrate, printing order, the black ink being used, and color saturation of the other three process inks.[8]

Unwanted color absorption of the printing inks must also be taken into account. When these deficiencies are considered, the unwanted color present in a process ink becomes the smallest proportion contributing to a particular shade of color, therefore this amount would be falsely used to figure the appropriate black replacement. Real printing inks contain impurities which produce unwanted color absorption; what works in theory does not always work in practice. An example is the magenta and yellow contamination in cyan ink. In practice these amounts are deducted from the cyan scanner signal and added back to the magenta and yellow signals before the gray-component replacement amount is programmed; this allows the true signal that makes the least contribution in forming a particular hue to be used to calculate the black ink replacement.[9]

Because area coverage is reduced separately in the gray and color areas of the reproduction, the black can be replaced in these areas separately from 0 to 100%; 100% being the maximum amount of gray-component replacement. Combinations between these extremes allow color reduction in both areas of the reproduction so that optimum results may be achieved during the individual press-run. When a large amount of GCR is used, the chromatic portion of process ink values for the reproduction must be increased because the achromatic portion is being replaced by a black which gives a different density reading than does a process color ink.[10]

There are several approaches used by the Hell Company to achieve gray-component replacement. The first, and most economical, follows a recommended set of procedures which the scanner operator can use while setting up the scanner for making the separations. A matrix can be placed over the dials of the scanner so that the operator can more easily interpret the prescribed procedures. This is necessary because the operator cannot make any judgment as to setup by taking measurements from the transparency; this is mostly due to inexperience when dealing with a new technique. The scanner operator is forced to follow the setup procedures, and is therefore limited to the amount of correction adjustment he can make. Before discussing other techniques for achieving achromatic reduction, mention must be made of the fact that the software used to achieve GCR requires the use of scanners with total digital control. The Hell Company's newer scanners, like the DC350, meet this requirement.[11]

The black box approach is a second method of utilizing GCR software. With this method the scanner operator follows his normal setup procedure, as he would for an original using no color reduction techniques. Prior to output recording from the computer, the analyzed data flows through the black box hardware and is then modified for GCR, or in the Hell Company's case, PCR.[12]

A third approach uses Hell's Chromacom system, Combiskop computer, and PCR software. The operator still takes necessary density readings from the original transparency to be reproduced and follows normal setup procedures. However, during the color correction stage, the operator dials in the appropriate percentages for achieving GCR. The picture information is thoroughly analyzed and then reprocessed for gray-component replacement.[13]

An 8 x 10 original, using a 150 line screen, requires approximately 32 megabytes of information for reproduction. The fact that each bit of this information must be first analyzed by the scanner's color computer and then reprocessed for GCR definitely adds a great deal to the time it takes to produce a set of color separations. The Hell Company has looked into high speed image processors like the BSP11, now being used for CAT scanners, to eliminate this problem. Hell will use these array processors with the Chromacom System to speed up the separation process; these processors perform highly complicated tasks at very rapid speeds.[14]

Hell's PCR hardware is now available for the newer scanners like the DC350. The transformation of the separation signals for all four printers is adjusted to new values for achieving gray-component replacement. This occurs in line with no extra scanning time nor extra operator judgment. Once the data is programmed into the scanner, the selection of GCR percentage is obtained by code number.[15]

The Hell Company has developed software packages that work in conjuction with their PCR software in an attempt to correct detail loss in the reproductions. At this point, as more and more gray-component replacement is used, contrast is affected and the reproduction becomes very flat in appearance. The new software is claimed to correct this problem by signaling the computer to add color back in certain areas where detail and contrast may decrease. PCR compensates for the ink used least in representing a tone, and the software is expected to compensate for ink deficiencies as well.[16]

Pertinent literature and opinions about the use of gray-component replacement will be discussed in the Literature Review section of this paper. This author has seen several examples of color reproductions, using various percentages of gray-component replacement. Her opinion, based on the samples seen, is that GCR can be carried too far, just as gray UCR can. In achromatic reproductions using maximum (100%) GCR in the darker areas of the reproduction, a definite shift in color can be seen when the reproduction is compared to a conventional four-color reproduction where no UCR is used. The use of the 100% black printer does improve detail and neutrality in the neutral areas of the reproduction, but print contrast is affected as the reproductions appear flat and lifeless next to the normal four-color reproduction. An attempt will be made to discover a percentage or threshold amount of GCR which is acceptable in comparison to a four-color reproduction where no undercolor removal is applied. The author suspects that the maximum amount of GCR (100%) will not be acceptable when compared to the traditional reproduction, nor to the original. The question of which reproduction method more exactly reproduces the original is also dealt with.

FOOTNOTES FOR CHAPTER TWO

[1]"Color Removal Revival", Printing World, 2Ø July 1983, p.16.

[2]"PCR: Programmed Color Reduction from Hell", Hell Company, 1983, p.3.

[3]Ibid.

[4]M. Winfried Lauenstein, "The Achromatic Method: What Changes Does It Bring?", presented at the XXVIIth. International Congress, Union des Industries Graphique de Reproduction, Cannes, France, 3Ø April 1983, pp. 2-3.

[5]Miles F. Southworth, "Hell Has Programmed Color Removal (PCR)", The Quality Control Scanner, Vol. 3, Number 6, (Livonia, New York:Graphic Arts Publishing Co., 1983), p. 4.

[6]Ibid.

[7]Gunter Keppler, "PCR-Programmed Colour Removal", Klischograph, 1982, p. 22.

[8]"PCR: Programmed Color Reduction from Hell", Hell Company 1983, p. 5.

[9]M. Winfried Lauenstein, "The Achromatic Method: What Changes Does It Bring?", presented at the XXVIIth. International Congress, Union des Industries Graphiques de Reproduction, Cannes, France, 3Ø April 1983, p.9.

[1Ø]Gunter Keppler, "PCR-Programmed Colour Removal", Klischograph, 1982, p. 23.

[11] Interview with Mr. Peter Daciuk, Technical Specialist, Hell Graphic Systems, Inc., White Plains, New York, January 1984.

[12]Ibid.

[13]Ibid.

[14]Ibid.

[15]Dr. Eggert Jung, Programmed and Complementary Color Reduction, (1984 TAGA Proceedings, Technical Association of the Graphic Arts, 1984), p. 148.

[16]Interview with Mr. Peter Daciuk, Technical Specialist, Hell Graphic Systems, Inc., White Plains, New York, January 1984.

CHAPTER THREE

LITERATURE REVIEW

Much of the technical literature on the subject of gray-component replacement has been mentioned in previous chapters. It should be cited however, that color specialists alluded to this correction methodology well before a technical means of achieving the actual separation films was available.

Philip Tobias explained in his 1954 paper, "A Color Correction Process", that "a method of color correction has been developed based on observation that any color within the gamut of the four-color process printing inks can be reproduced by pairs of the chromatic inks plus black". He said, "...it is evident that graying or reductions in the luminance can be obtained by adding black to the binary mixture", instead of a third process ink.[1]

Harald Kueppers, another pioneer of achromatic theory, gives theoretical explanations for achromatic color mixtures using black ink in his Color Atlas: A Practical Guide for Color Mixing. Kueppers says:

> it is a worldwide custom today to use a chromatic mixture in multi-color printing. (His) book is proof of the fact that this is the worse of two technological possibilities. Color charts with the black structure prove that the

> conversion to genuine four-color printing will bring enormous technological and economic advantages. Everyone will clearly realize that it certainly makes sense to build up the achromatic values of a particular hue as much as possible on the basis of black.[2]

Kueppers says printing with eight colors would be the logical answer (cyan, magenta, yellow, red, green, blue, black, and white), however for practical purposes, no printer could ever perfect this technique. Using the standard four process inks, these eight colors can be achieved. With achromatic printing, theoretically,

> in any one area you will only ever get two of the printing colors plus black. So green, red, and blue together equal a gradation of white and areas of no value equal gradations of black. Only the values between these extremes form the gradations of chromatic color.[3]

John Yule explains in his Principles of Color Reproduction, published in 1976,

> the idea of using 100% UCR...is attractive, and here the grays would be carried entirely in the black plate, and no area would contain more than two colors plus black. However, this is not a practical system because the maximum density of the blacks would be insufficient, and because the slightest misregister would cause white lines to appear between black and colored areas.[4]

As mentioned before however, chromatic values are being increased to compensate for density differences between the black and color inks. Black inks are also being specially formulated and tested to achieve the appropriate density required by GCR.

In a conversation with George Leger, Technical Manager for Dupont, Mid-West Region, who spent a month in Germany to study Offset/Gravure conversion and was exposed to gray-component replacement techniques, it was clear that this reproduction method is being studied for its application in commercial printing. Mr. Leger was impressed by the interest shown in meetings and seminars dealing with the subject of GCR. Companies, The Gillette Company included, are requesting the use of this reproduction method for their commercial printing needs. European and American trade shops are using the technique as a marketing tool in an effort to create customer interest.[5]

Initially, it was thought that GCR would offer large cost savings in ink, however, this is not always true. For example, to reproduce a deep purple, if yellow ink is removed and replaced with black ink, an increase in the cyan and magenta may be called for in order to achieve the correct shade of purple. Ink savings are therefore not as much a consideration as the quality and ease of printing. To reproduce a particular color, variations in density are critical with three colors. The use of two colors plus black eliminates some of the density variations. As pointed out during the interview, colors like beige or brown which are sensitive to color shifts are difficult to reproduce using the three color inks. To achieve a certain hue, the printing surface must perfectly match the one appropriate square of a color chart illustrating that particular hue of a color. Two colors plus black are less sensitive to color shifts, and a color that normally requires critical balance, with four-color printing, may match color hue to four or more patches on a color chart while closely enough reproducing the original color shade with achromatic printing.[6]

It is Mr. Leger's opinion that the theory works and, with the correct programs for achieving GCR and the proper degree of reduction, the technique can prove to be a viable tool for the entire printing industry. He believes, based on his viewing of samples, that the programs for GCR are being continually perfected and the print quality is improving at the same time. Whether the quality improves enough is the question. It is also possible however, that Europeans, who actually made the initial push toward achromatic color, are not quite as advertising agency oriented as are the Americans, and that the quality expected for process color may be different for this reason.[7]

Four-color newspaper printers should find uses for GCR in their efforts to control color shifts; the control of ink densities on newsprint is often a problem. Mr. Leger is working in the field of offset/gravure conversion, and feels that GCR will be of help in matching color between offset proofs and gravure proofs.[8]

Although gray-component replacement offers technical and cost benefits, some disadvantages are recognized. The color separation sets have an unusual appearance compared to traditional four-color films. Dot etching is also a problem. If the least dominant chromatic printer is totally replaced with black, dot etching corrections cannot be made in favor of that particular color because it no longer exists in the separation films. For this reason, cyan, magenta, and yellow should be left in all areas of the reproduction. Also, the screen structure can be more recognizable in these films. As mentioned earlier, misregistration can be a problem; if GCR is pushed close to 100% a white line could appear around objects not in register.[9]

During the last thirty years, the industry has moved from theoretical descriptions to practical application of gray-component replacement techniques. M. Winfried Lauenstein spoke of the present state of the art in West Germany in a paper written for the Union International des Industries Graphiques de Reproduction. He explained that large printing and electronic industries as well as various reproduction firms have been actively researching the possibility of adapting GCR. Testing has been done by individual firms to find their own optimum relationship among inks, substrates, and amounts of GCR. He said, "it is possible to note that all well known firms are, at least theoretically, developing the achromatic method."[10]

The same testing has been taking place in the United States. In theory GCR can help standardize high speed printing. The question as to whether this method, with its cost and technical benefits, can produce acceptable print quality must continue to be examined by the graphic industries before decisions can be made in favor of its widespread use.

FOOTNOTES FOR CHAPTER THREE

[1]Philip E. Tobias, A Color Correction Process, (1954 TAGA Proceedings, Technical Association of the Graphic Arts, 1954), p. 85-90.

[2]Harald Kueppers, Color Atlas: A Practical Guide For Color Mixing, (Cologne, West Germany: Dumont Buchvelag GmbH & Co., 1982), p. 132.

[3]Ibid.

[4]J.A.C. Yule, Principles of Color Reproduction, (New York: John Wiley & Son, Inc., 1976), p. 296.

[5]Telephone interview with Mr. George Leger, Technical Manager; Mid-West Region, Dupont-Photo Products Division, Chicago, Illinois, January 1984.

[6]Ibid.

[7]Ibid.

[8]Ibid.

[9]Dr. Eggert Jung, Programmed and Complementary Color Reduction, (1984 TAGA Proceedings, Technical Association of the Graphic Arts, 1984), p. 136.

[10]M. Winfried Lauenstein, "The Achromatic Method: What Changes Does It Bring?", presented at the XXVIIth. Internationaly Congress, Union des Industries Graphiques de Reproduction, Cannes, France, 30 April 1983, p. 4-5.

CHAPTER 4

HYPOTHESES

The experimental objectives and considerations can be stated as follows:

Hypothesis 1. There is a limit to the amount of gray-component replacement that can be used to reproduce acceptable color. (This is determined by comparison to the conventional four-color reproduction method, already proven to be acceptable by its wide use in the printing industry.)

Restated:

> H_0: There is no noticeable visual difference between the two color separation techniques.
>
> H_1: There is a difference between the two color separation techniques that will indicate the limit of gray-component replacement which can be used to reproduce acceptable color.

Hypothesis 2. A conventional four-color reproduction, without the application of undercolor reduction, is more exact in reproducing an original transparency than is a reproduction using gray-component replacement techniques.

Restated:

> H_0: There is no noticeable difference between the two color separation techniques.
>
> H_1: Among those who see a difference, the

conventional four-color reproduction method is preferred.

The first objective of this experiment was to find an acceptable amount of GCR which can be used in the preparation of process color separations for four-color printing. In order to achieve acceptable results, the achromatic reproduction must be viewed in comparison to a traditional four-color reproduction as being an equal if not higher quality color reproduction. A "normal" or "conventional" four-color reproduction was produced without the use of any undercolor reduction. The second objective was to determine which of the two reproduction methods more accurately reproduces the original transparency.

CHAPTER FIVE

METHODOLOGY

The following methodology was employed in order to test the proposed hypotheses forming the basis for this research project. For the purpose of explanation, the methodology will be reduced to several steps.

Step 1. A color transparency was first photographed for color separation purposes. This transparency became the standard original copy for testing the hypotheses. The original was photographed using Ektachrome 64, 4 x 5, Daylight film. It was specified to the photographer that the photograph be a low key transparency, so that the effects of GCR were recognizable. A low key transparency is a dark transparency that contains important shadow detail. The objects in the transparency photographed were carefully selected for two reasons. First, it was important to use objects that the viewer could easily identify, such as flesh tones, memory colors, and a well known logo. Memory colors are colors used to represent such objects found in nature as red apples, blue skies, and green grass. Even the untrained eye can recognize a false rendering of these colors. Second, the objects also needed to show important tone reproduction qualities such as detail, contrast, and color rendition. The wide variety of props was selected to illustrate these qualities, while at the same time remaining partial to neither the GCR method nor the conventional four-color reproduction method.

Step 2. The original transparency was sent to Hell Graphic Systems, Inc. so that the appropriate color separations could be made. The digital color computer of Hell's DC350 scanner utilizes the necessary software for achieving GCR. At the time this requirement could not be met with any of the existing equipment in the School of Printing at R.I.T. A normal four-color separation, using no UCR, was reproduced following prescribed specifications requested by the author. Specifications included a highlight to midtone density range of 1.00, printing dot requirements, as well as the lightest density of the transparency that should be used to program the highlight dot requirements.

In an attempt to control variability, the achromatic separations were made from the same transparency on the same scanner, as was the four-color separation with no undercolor reduction. This helped assure that the color computer in the scanner remained a constant variable. Reproductions with 25%, 50%, 75%, and 100% GCR were reproduced, again from the original transparency. These percentages were chosen to illustrate minimum and maximum effects of GCR, allowing the viewer to see both extremes when comparisons were made to the normal reproduction and the original.

Step 3. After the separations were received, they were gang proofed using the DuPont Cromalin Proofing System, with specified SWOP toners. The DuPont Cromalin Offset Com Guides-System Brunner was used to keep exposure constant. After the application of each toner, the proofs were exposed for 21 units. A final exposure of 65 units completed the proofs.[1] A reflection densitometer aided in the attempt to keep density constant. The densities after each application of toner read: .90 yellow, 1.28 cyan, 1.30 magenta, and 1.30 black.[2] This was a strict requirement for proofing.

Step 4. Once proofing was completed, a random selection of viewers was asked to participate in the testing process. The viewers were R.I.T. students in the School of Printing. The majority had very little training in the areas of advanced tone reproduction and color separation. The only prerequisite was normal color vision. Each viewer was required to take a color vision test until 30 viewers with favorable results were found. This author used the AO H-R-R Pseudoisochromatic Plates to screen for color blindness. The plates are supplied by the American Optical Corporation and are based on recognized research of several committees specializing in physiological optics, color, and color blindness studies. These plates are considered an accepted means for differentiating between normal color vision and defective color vision.[3]

Several criteria were used in setting up the testing area for standardization and to eliminate any psychological distractions. All viewers examined color under like conditions. First, all those tested were asked to view the proofs at the viewing booth under a standard color temperature light of 5,000 degrees Kelvin. The proofs were mounted on a neutral gray background. The transparency was shown on the light box illuminated from behind. None of the viewers was told at any time during the survey which reproduction method was used to produce the proofs under examination. The proofs were shown in a random order so the viewer never assumed a specific pattern. When the original transparency was shown with the proofs, it was shown in the center over the two proofs, so the original was never closer to one proof than the other. These standards remained constant throughout the testing process.

Hypothesis 1. The viewer was asked to view all five proofs (normal, 25%, 50%, 75%, and 100% GCR) in random order and rank them from highest to lowest ranking order for five different categories: detail, sharpness, flatness, color, and overall appearance. The ranking order was recorded on the survey sheet specially devised to complement the statistical method applied. The data were analyzed to see if one separation method was preferred over the other and if so, was there a recurring percentage of GCR considered acceptable by a majority of the viewers.

Hypothesis 2. The viewer compared the reproductions using different percentages of GCR, and the normal reproduction, to the original transparency one at a time. A paired comparison method was used to see which reproduction technique more accurately reproduced the original copy. The viewer was asked which reproduction most closely matched the original transparency. He or she was also asked to examine such features as detail, image sharpness, and contrast. The data were collected and statistically analyzed to determine which reproduction method most accurately reproduced the original transparency.

SURVEY QUESTIONNAIRE

Section I

Rank the five reproductions from highest to lowest ranking order for each of the following:

1. Most accurate detail in the objects photographed

A	B	C	D	E

2. Sharpness or crispness

A	B	C	D	E

3. Largest amount of intermediate tones from the highlight to the shadow reqions of the reproduction, (the flatter the reproduction, the lower the ranking order)

A	B	C	D	E

4. In terms of color, rank as to order of preference

A	B	C	D	E

5. Based on the overall appearance of the reproductions, rank as to order of preference

A	B	C	D	E

Section II

1. Which reproduction possesses the most accurate detail in the objects photographed, when compared to the original transparency?

A B same

A C same
A D same
A E same

2. Which reproduction appears sharper or more crisp when compared to the original transparency?

A B same
A C same
A D same
A E same

3. Which reproduction more accurately illustrates the differences in tones from the highlight to the shadow regions of the reproduction when compared to the original transparency? (Which reproduction is noticeabley flatter than the original transparency?)

A B same
A C same
A D same
A E same

4. In which reproduction do the reproduced colors more exactly match the colors of the original transparency?

A B same
A C same
A D same
A E same

5. Which reproduction comes closer to reproducing the original transpanency?

A B same
A C same
A D same
A E same

FOOTNOTES FOR CHAPTER FIVE

[1] Joseph Noga, Scanner Seminar Class Notes, Rochester Institute of Technology, Winter 1984.

[2] Ibid.

[3] LeGrand H. Hardy, Gertrude Rand, and M. Catherine Rittler, AO H-R-R Pseudoisochromatic Plates, (USA: American Optical Corporation, 1957).

CHAPTER SIX

DATA ANALYSIS

Survey data were taken from the questionnaire forms and statistically analyzed according to predetermined statistical methods.[1] The data may be seen in Tables 1 through 1Ø.

Anaylsis of Hypothesis I

Statistical Method: Monova on ranks; Friedman's Test (randomized complete block design)

Statistical Notes: Each of b judges rank 5 proofs by certain criteria. A table can be devised:

Viewer	A	B	C	D
1	r_{11}	r_{12}	r_{13}	
2	r_{21}	r_{22}	r_{23}	
.				
b	r_{b_1}	r_{b_2}	r_{b_3}	
	R_1	R_2	R_3	

where r_{ij} is the rank given by judge i to treatment j.

$R_j = \sum_{i=1}^{b} r_{ij}$ is the sum of the ranks assigned by all viewers to treatment i. Assuming no differences between treatments, then the ranks assigned by the judges should be nothing more than random permutations of the numbers 1, 2, 3, 4 and 5 (a moderate number of ties is permitted). Since the average rank is $3 = \frac{1+2+3+4+5}{5}$, one would expect if there are no differences that each R_j would be approximately equal to 3b. Friedman's test determines the extent to which the sequence

$$(R_1, R_2, R_3, R_4, R_5)$$

differs from the sequence

$$(3b, 3b, 3b, 3b, 3b).$$

This assumes the judges act independently.

Friedman's Statistic:

$$A_2 = \sum_{i=1}^{b} \sum_{j=1}^{5} r_{ij}^2$$ sum of squares of table entries

$$B_2 = \frac{1}{b} \sum_{j=1}^{5} Rj^2$$ average square of column sums

$$T_2 = \frac{(b-1)\,[B_2 - 45b]}{A_2 - B_2}$$ Friedman's Statistic

Decision Rule: Look T_2 up in F distribution table

$$F_{4,\ 4(b-1)}$$

If Friedman's test results in a rejection of the null hypothesis--proceed to test differences between individual treatments as follows:

treatments i and j are considered to be different if:

$$\left|R_i - R_j\right| > t_{1-\frac{\alpha}{z}} \left[\frac{2b\,(A_2 - B_2)}{4(b-1)} \right]^{\frac{1}{2}} \quad 2$$

To test for hypothesis I, 30 viewers ranked 5 proofs from highest to lowest ranking order for 5 different criteria. Number 1 was the highest ranking order while number 5 was the lowest.

Question 1--Rank in order of most accurate detail in the objects photographed. (1 = most accurate detail; 5 = least accurate detail).

<u>Table 1</u>

(Data from survey question 1)

<u>Viewer</u>	A	B	C	D	E
1	2	3	4	1	5
2	5	1	3	2	4
3	5	2	4	1	3
4	1	5	4	2	3
5	1	2	4	5	3

6	5	3	4	2	1	
7	1	2	4	3	5	
8	1	2	3	4	5	
9	5	3	1	2	4	
10	1	2	3	4	5	
11	5	4	2	1	3	
12	5	4	3	2	1	
13	5	2	4	1	3	
14	1	5	4	3	2	
15	1	4	2	3	5	
16	5	3	4	2	1	
17	1	5	4	2	3	
18	1	2	4	5	3	
19	3	5	4	2	1	
20	4	5	3	2	1	
21	1	3	2	5	4	
22	1	2	3	4	5	
23	5	2	4	3	1	
24	1	2	4	5	3	
25	4	5	3	2	1	
26	2	1	4	3	5	
27	1	3	2	4	5	
28	3	5	4	1	2	
29	1	2	5	4	3	
30	4	1	5	3	2	
						Totals
Sum of squares	313	324	386	279	348	= 1,650
Sum of columns	81	90	104	83	92	= 450
Sum of columns squared						= 40,830

Decision rule: $T_2 = 1.1038$
$F(K-1), 4(b-1)$
$F(5-1), 4(30-1)$ F Table = 2.49
$F_4, 4(29)$
$F_4, 116$

Results: T_2 does not exceed the .95 quantile of the F distribution, therefore can not reject H_0. According to test, there is no significant difference.

Question 2--Rank in order of sharpness or crispness. (1 = most sharp or crisp; 5 = least sharp or crisp).

Table 2

(Data from survey question 2)

Viewer	A	B	C	D	E
1	3	5	2	1	4
2	4	5	1	2	3
3	3	4	2	5	1
4	1	5	3	2	4
5	2	1	4	5	3
6	5	3	1	4	2
7	1	2	3	5	4
8	1	2	3	4	5
9	5	4	3	1	2
10	1	2	3	5	4
11	4	5	3	2	1
12	3	4	5	1	2
13	5	4	2	1	3
14	4	3	1	2	5
15	5	3	4	1	2
16	5	4	3	2	1
17	1	2	3	5	4
18	2	1	3	4	5
19	4	5	2	3	1
20	1	5	3	2	4
21	1	2	3	4	5
22	2	1	3	4	5
23	1	3	5	4	2
24	3	4	5	2	1
25	1	5	2	3	4
26	5	1	2	3	4
27	1	2	4	3	5
28	2	4	1	3	5
29	1	2	3	4	5
30	1	3	2	4	5

	A	B	C	D	E		Totals
Sum of squares	278	364	272	331	405	=	1,650
Sum of columns	78	96	84	91	101	=	450
Sum of columns squared						=	40,838

Decision rule: $T_2 = 1.1038$ F Table = 2.49

Results: T_2 does not exceed the .95 quantile of the

F distribution, therefore can not reject $H_{\emptyset}$. According to test, there is no significant difference.

Question 3--Rank in order of greatest amount of intermediate tones from highlight to shadow regions of the reproduction. (1 = greatest amount; 5 = least amount).

Table 3

(Data from survey question 3)

Viewer	A	B	C	D	E
1	3	2	5	1	4
2	5	3	1	2	4
3	5	1	3	4	2
4	5	4	1	3	2
5	5	1	3	4	2
6	1	4	5	3	2
7	5	4	3	2	1
8	5	4	1	3	2
9	1	3	2	5	4
1∅	4	5	3	2	1
11	5	4	3	2	1
12	5	4	2	1	3
13	4	2	5	3	1
14	5	3	4	2	1
15	5	1	3	4	2
16	4	3	5	1	2
17	5	4	3	2	1
18	5	4	3	2	1
19	5	3	4	1	2
2∅	3	4	1	2	5
21	5	4	3	2	1
22	5	4	2	3	1
23	5	3	4	2	1
24	4	2	1	5	3
25	5	4	3	1	2
26	3	4	1	2	5
27	5	2	4	1	3
28	5	4	2	1	3
29	5	4	2	3	1

30	1	4	2	5	3		Totals
Sum of squares	594	354	284	228	190	=	1,650
Sum of columns	128	98	84	74	66	=	450
Sum of columns squared						=	42,876

Decision rule: T_2 = 10.367 F Table = 2.49

Results: T_2 exceeds the .95 quantile of the F distribution, therefore H_0 is rejected. Continue to test H_1, conditional alternative.

Results: 2 whose rank sums are greater than 10.69 units apart may be regarded as unequal.

D and E must be considered as equal;

ranking order 1 to 5;

A has fewer intermediate tones than B and B fewer than C.

Question 4--Rank in order of preference in terms of color. (1 = most preferred; 5 = least preferred).

Table 4

(Data from survey question 4)

Viewer	A	B	C	D	E
1	5	4	3	1	2
2	5	4	1	3	2
3	1	2	3	4	5
4	1	2	3	5	4
5	1	2	4	5	3
6	5	4	2	3	1
7	1	2	3	4	5
8	1	2	3	4	5

9	5	4	1	2	3	
10	1	2	3	5	4	
11	5	1	3	4	2	
12	5	1	3	2	4	
13	5	4	2	1	3	
14	5	1	2	3	4	
15	4	2	3	1	5	
16	1	2	3	4	5	
17	5	3	4	2	1	
18	2	1	3	4	5	
19	1	2	3	5	4	
20	3	1	4	2	5	
21	1	2	3	4	5	
22	2	1	3	4	5	
23	4	3	5	1	2	
24	5	3	2	4	1	
25	1	2	3	5	4	
26	4	3	5	2	1	
27	1	2	3	4	5	
28	1	2	3	4	5	
29	1	2	4	3	5	
30	1	2	4	3	5	
						Totals
Sum of squares	329	182	301	370	468	= 1,650
Sum of columns	83	68	91	98	110	= 450
Sum of columns squared						= 41,498

Decision rule: T_2 = 3.58 F Table = 2.49

Results: T_2 exceeds the .95 quantile of the F distribution, therefore, continue to test H_1, the conditional alternative.

2 whose rank sums are greater than 11.75 units apart may be regarded as unequal.

C and D must be considered equal;

B is more preferred than A;

A is more preferred than E.

Question 5--Rank in order of preference based on overall appearance of the reproductions. (1 = most preferred; 5 = least preferred).

Table 5

(Data from survey question 5)

Viewer	A	B	C	D	E	
1	1	3	2	5	4	
2	5	2	3	1	4	
3	1	2	5	3	4	
4	4	1	2	3	5	
5	1	2	3	4	5	
6	5	4	2	3	1	
7	1	2	3	4	5	
8	1	2	3	4	5	
9	5	3	1	2	4	
10	2	1	3	4	5	
11	4	3	2	1	5	
12	5	4	1	2	3	
13	5	1	3	4	2	
14	3	4	2	1	5	
15	4	2	1	5	3	
16	5	2	1	4	3	
17	1	2	3	4	5	
18	1	2	3	5	4	
19	3	5	1	2	4	
20	1	2	3	4	5	
21	1	2	3	5	4	
22	1	2	4	3	5	
23	4	3	2	1	5	
24	5	4	2	1	3	
25	1	2	4	3	5	
26	2	1	4	5	3	
27	2	4	1	3	5	
28	1	2	3	4	5	
29	1	2	4	3	5	
30	4	1	3	2	5	
						Totals
Sum of squares	298	206	231	353	562	= 1,650
Sum of columns	80	72	77	95	126	= 450
Sum of columns squared						= 42,414

Decision rule: T_2 = 7.86   F Table = 2.49

Results: T_2 exceeds the .95 quantile of the F distribution, therefore, continue to test H_1, the conditional alternative.
2 whose rank sums are greater than 11.05 units apart may be regarded as unequal.
A and B must be considered equal;
Ranking order 1 to 5; C, D, & E decrease in ranking order of preference.

Analysis of Hypothesis II

Statistical Method: Binomial Distribution[3]

Statistical Notes: testing the null hypothesis H_0 that P = P_0 (P is the perameter of the binomial distribution)

H_0: $p = p_0$

H_1: $p < p_0$

H_0: no difference between separation techniques

H_1: (conditional alternative) among those who see a difference, a conventional four-color reproduction more exactly reproduces the original transparency

A = conventional four-color reproduction

B = 25% GCR

C = 50% GCR

D = 75% GCR

E = 100% GCR

Question 1--Which reproduction has the most accurate detail in the objects photographed?

Table 6

(Data from survey question 1)

	B	C	D	E
Conventional	12	14	15	12
GCR	18	16	11	17
Same	0	0	4	1

1.

H_0: $p = .5$

H_1: $p > .5$

$\alpha = .05$ (significance level)

critical region: all x values such that P_r ($X \geq 12/H_0$ is true) $< .05$

$x^1 = 12$ (number of people choosing conventional four-color separation method)

$n = 30$ (sample size)

$\Theta = .5$ (probability of null hypothesis)

$$\sum_{x=x^1}^{n} \binom{n}{x} \Theta^x (1-\Theta)^{n-x} = \binom{30}{12}(.5)^{12}(.5)^{18} + \binom{30}{13}(.5)^{13}(.5)^{17} + \cdots \binom{30}{30}(.5)^{30}(.5)^{0}$$

<u>CRC-Handbook of Tables for Probability and Statistics</u>
--Individual terms, Binomial Distribution Tables[4]

value = .8998 (can not reject H_0 because .8998 is not greater than .05)

2.

$x^1 = 14$

$n = 30$ (table value is $.7077 \nless .05$)

$\theta = .5$

3.

$x^1 = 15$

$n = 26$ ($.3922 \nless .05$)

$\theta = .5$

4.

$x^1 = 12$

$n = 29$ ($.7774 \nless .05$)

$\theta = .5$

Results: For question 1, in no case can H_0 be rejected, there is therefore no significant difference.

Question 2--Which reproduction appears sharper or more crisp when compared to the original transparency?

Table 7

(Data from survey question 2)

	B	C	D	E
Conventional	15	13	12	10
GCR	12	16	17	17
Same	3	1	1	3

Results: For question 2, in no case can H_0 be rejected, there is therefore no significant difference.

Question 3--Which reproduction more accurately illustrates the difference in tones from the highlight to the shadow regions of the transparency? (which reproduction is noticeably flatter than the original transparency?)

Table 8

(Data from survey question 3)

	B	C	D	E
Conventional	15	17	15	17
GCR	13	12	13	9
Same	2	1	2	4

Results: For question 3, in no case can H_0 be rejected, there is therefore no significant difference.

Question 4--In which reproduction do the colors most exactly match the colors of the original transparency?

Table 9

(Data from survey question 4)

	B	C	D	E
Conventional	14	9	12	15
GCR	16	21	18	14
Same	0	0	0	1

Results: For question 4, in no case can H_0 be rejected, there is therefore no significant difference.

Question 5--Which reproduction comes the closest to matching the original transparency?

Table 10

(Data from survey question 5)

	B	C	D	E
Conventional	15	16	15	14
GCR	14	13	15	16
Same	1	1	0	0

Results: For question 5, in no case can H_0 be rejected, there is therefore no significant difference.

FOOTNOTES FOR CHAPTER SIX

[1]Paul Wilson, School of Mathematics, Rochester Institute of Technology, Spring, 1984.

[2]W. Conover, Practical Nonparametric Statistics, (New York: John Wiley & Sons, Inc., 1980) p. 299.

[3]Ronald E. Walpole and Raymond H. Myers, Probability and Statistics for Engineers and Scientists, (New York: The Macmillan Company, 1972), p. 259.

[4]William H. Beyer, Ph.D., CRC Handbook of Tables for Probability and Statistics, (Cleveland, Ohio: The Chemical Rubber Co., 1968), p. 195.

CHAPTER SEVEN

DISCUSSION OF RESULTS

The experimental objectives and considerations again were broken into two main hypotheses. The researcher intended to illustrate, by visual means, that only a particular percentage or degree of gray-component replacement can be used to produce a "quality" or visually pleasing color reproduction. Subjective viewing in this case did not absolutely prove this hypothesis. Questions regarding detail in the objects photographed and in sharpness or crispness of reproduction showed that most viewers were not able to see a significant difference between the two separation methods. Studying the data, one can see that more of the viewers gave favorable responses toward the traditional chromatic reproduction. There was not enough difference in responses to reject the null hypothesis however.

The viewers were able to see a difference when asked which reproduction had the largest amount of intermediate tones from the highlight to the shadow regions of the reproduction, or restated, if one reproduction appeared noticeably flatter in appearance than another. The chromatic reproduction was shown to be less flat in appearance than the reproductions produced with varying amounts of GCR. The higher the degree of GCR, the flatter the appearance. Viewers were not able to detect a noticeable difference between reproductions achieved with greater percentages of GCR, that is, they could not tell a difference between 75% GCR and 100% GCR. The differences were seen between the chromatic reproduction, 25% GCR and 50% GCR.

When viewers were asked to rank in order of preference concerning color, a difference was also seen. Many viewers preferred the chromatic reproduction; this can be seen by studying the data in Table 4. Viewers also found the color of reproduction B appealing. This reproduction was produced using the lowest degree of GCR. Some viewers even found the reproduction produced with 100% GCR appealing in terms of color. Viewers were not able to see a difference when intermediate amounts of GCR were used, such as 50% to 75% GCR.

Finally viewers were asked, on the basis of overall appearance, to rank the reproductions. A preference difference was not found between the chromatic reproduction and the reproduction produced with the least degree of GCR. Reproductions achieved with 50% GCR, 75% GCR, and 100% GCR, continually decreased in ranking order of preference.

A second object of the research was to show that a conventional four-color reproduction is more exact in reproducing original artwork than is a reproduction produced by gray-component replacement methods. Based on five different criteria, viewers were asked to compare each degree of GCR reproduction and the chromatic reproduction to the original transparency. The criteria were: most accurate detail, sharpness, flatness of reproduction, color, and overall appearance when compared to the original transparency. In all cases, the null hypothesis could not be rejected. The average viewer saw no significant difference between color separation methods when compared to the original art. With a sample size of thirty, the number of people choosing the conventional four-color reproduction method must be greater than twenty to reject the null hypothesis in favor of the alternative.

CHAPTER EIGHT

SUMMARY AND CONCLUSIONS

Certain conclusions can be made based on this research. While not all the visual or tone reproduction criteria proved favorable to the traditional four-color separation method, several important factors must be stressed. The subjective survey did illustrate that print contrast is affected. As greater amounts of GCR are used in the separation process, the reproductions become flatter in appearance. The extreme use of GCR removes too much of the colored ink needed for density, saturation, and contrast.

The research also shows that more viewers preferred, on the basis of color and overall appearance, the chromatic reproduction or reproduction using smaller degrees of gray-component replacement. One explanation for a visual difference in color as greater amounts of GCR are used may be explained by the occurrence of shifts in hue. When large amounts of opaque black ink overprint one or more of the transparent chromatic inks it causes an increase in unwanted absorption while simultaneously decreasing the desired absorption when trying to reproduce a particular color. This problem is not as apparent when the traditional skeleton black printer is used in the shadow areas of the reproduction. When large amounts of UCR or GCR are used, hue shifts become more of a problem.[1] The author should add that results may have been more revealing had the separation films used in this research been produced by someone independent of GCR economics.

Even though the strong use of black can improve detail and neutrality, appearance of color and contrast are two very important factors in the reproduction process. Extreme levels of gray-component replacement are not recommended for critical color reproduction work. High quality commercial printing depends on exacting results when reproducing a customer's original artwork. Again, the problem of color correction or dot etching should be mentioned. As chromatic inks are reduced or removed from the separation film, it makes color correction more difficult. In some cases, customer requested corrections would become impossible if one of the chromatic printers were totally eliminated.

Gray-component replacement offers many technical and cost benefits to the graphic industries. Continued research, experimentation, and education will lead to an appropriate increased employment of this separation method; GCR will find its niche in the industry.

FOOTNOTE FOR CHAPTER EIGHT

[1]Brian Philippsen, "The Effects On Hue Resulting From Black Overprinting In Halftone Reproductions", Master's Thesis, Rochester Institute of Technology, May 1985.

CHAPTER NINE

RECOMMENDATION FOR FURTHER STUDY

Research in the area of gray-component replacement separation techniques must continue to take place before this technique is widely accepted in all areas of the printing industry. This author suggests the following:

1. Repeat the following research, however all separation work should be done by the researcher in the lab at R.I.T. The researcher would have better control over the experiment, less variability, and more accurate results.

2. Test the claimed cost benefits of GCR such as: less ink consumption, faster drying time, reduced make-ready time, better results in pressroom and print finishing departments.

3. Make a comparison between the use of GCR for the high quality commercial printer versus the printer specializing in less critical color work (ie., less dot etching, lower grades of stock, less critical registration, etc.).

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